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ENVIRONMENTAL HEALTH SERIES
Water Supply
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FEASIBILITY OF GRANULAR, ACTIVATED-CARBON ADSORPTION FOR WASTE-WATER RENOVATION

AWTR-10

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Advanced Waste Treatment Research Publications

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FEASIBILITY OF GRANULAR, ACTIVATED-CARBON ADSORPTION FOR WASTE-WATER RENOVATION

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for

The Advanced Waste Treatment Research Program
Basic and Applied Sciences Branch
Robert A. Taft Sanitary Engineering Center

A report submitted in fulfillment of a contract between the Public Health Service and Pittsburgh Chemical Company. (Contract Number SAph 86-62-15 for the period September 20, 1961 - September 19, 1962.) Submitted July 1962.

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Public Health Service
Division of Water Supply and Pollution Control

May 1964

The ENVIRONMENTAL HEALTH SERIES of reports was established to report the results of scientific and engineering studies of man's environment: The community, whether urban, suburban, or rural, where he lives, works, and plays; the air, water, and earth he uses and re-uses; and the wastes he produces and must dispose of in a way that preserves these natural resources. This SERIES of reports provides for professional users a central source of information on the intramural research activities of Divisions and Centers within the Public Health Service, and on their cooperative activities with State and local agencies, research institutions, and industrial organizations. The general subject area of each report is indicated by the two letters that appear in the publication number; the indicators are

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Public Health Service Publication No. 999-WP-12

ADVANCED WASTE TREATMENT RESEARCH PROGRAM

The Advanced Waste Treatment Research Program of the Public Health Service has two ultimate goals: One is to help abate our Nation's growing water pollution problems, and the other, more startling in concept, is to renovate waste water for direct and deliberate re-use.

Conventional water and waste treatment practices have little or no effect on many simple inorganic salts and permit an ever-increasing number and amount of highly complex, synthetic organic wastes to contaminate drinking water supplies. If we are to protect these water supplies for the future, it is mandatory that new technologies for water and waste treatment be developed.

Advanced Waste Treatment may be looked upon as a two-step process: (1) Separating concentrated contaminants from the purified water "product," and (2) disposing of the concentrated contaminants in a way that will render them forever innocuous. This "permanent disposal" of separated wastes is essential so that useable surface or ground waters will not be contaminated and so that the same contaminants need not be removed again and again from water supplies.

In one step, then, advanced waste treatment, i.e., water renovation, could alleviate both water pollution and water supply problems – problems of increasing concern both in this country and in the rest of the world. The importance of advanced waste treatment was recognized by Congress in its 1961 amendments to the Federal Water Pollution Control Act (Public Law 87-88). This act directs the Secretary of Health, Education, and Welfare " . . . to develop and demonstrate practicable means of treating municipal sewage and other water-borne wastes to remove the maximum possible amounts of physical, chemical, and biological pollutants in order to restore and maintain the maximum amount of the Nation's water at a quality suitable for re-use."

It is too early to predict accurately the cost of advanced waste treatment technology, but the need is inevitable. Because of population increase and industrial expansion, we are approaching the time when our rivers and streams will no longer be able to assimilate our wastes and when there will be no more developable supplies of fresh water. Whatever the cost of this technology, one thing is certain – it must be the very lowest science and engineering can achieve. Anything more will impose an

inexcusable, perhaps intolerable burden on our country's economic growth and on its ability to compete in tomorrow's world.

Pittsburgh Chemical Company is a subsidiary of Pittsburgh Coke and Chemical Company of Pittsburgh, Pennsylvania. The company, one of seve[illegible]ompanies that make activated carbon in the United States, produces carbon for decolorizing and liquid purifying. The only company commercially manufacturing activated carbon from coal, Pittsburgh Chemical Company has been particularly active in the use of granular, activated carbon for water treatment. Mr. Joyce and Mr. Sukenik are supervisor and technologist, respectively, in activated carbon research, Research and Development Department.

The authors are indebted to the Pleasant Hills Authority for permission to conduct the column tests at their Treatment Plant, in particular to Mr. Richard S. Dodds, Plant Superintendent, and his staff for their help and cooperation during the tests. Thanks are also due to Mr. William Rovesti for the isotherm tests, to Miss Jayne Schmitt and Mrs. Frances Brunner for the ABS and COD determinations, and to Dr. J. V. Fisher for the economic analyses.

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ABSTRACT

Granular, activated carbon in packed-bed column contactors was shown to remove much of the organic matter including alkylbenzenesulfonate from municipal waste water. The COD of a secondary effluent was reduced to about 12 to 20 ppm and the ABS was removed almost entirely. When an ABS breakthrough concentration of 0.5 ppm is used as a criterion of carbon exhaustion, the amount of carbon required for countercurrent contacting is less than 1 pound per 1,000 gallons. For the process to be economical the carbon must be reactivated and re-used. Thermal reactivation in a steam-air atmosphere was found to be technically feasible. With reactivation, the total cost of carbon adsorption was estimated to be less than 10 cents per 1,000 gallons for plants treating 10 mgd of waste water.

GPO 811-666-2

FEASIBILITY OF GRANULAR, ACTIVATED-CARBON ADSORTION FOR WASTE-WATER RENOVATION

Introduction

Conventional waste-water treatment methods do not remo e all the soluble compounds in the raw waste water. Inorganic materials are not appreciably affected and even highly biologically treated effluents contain 50 to 150 ppm of organic materials. The ultimate objective of this research program is to establish the economic feasibility of removing the organic matter from secondary waste-water effluents by using granular, activated carbon in a column process.

Although there was little doubt that activated carbon would adsorb the organic matter from waste effluents, it had not been established that use of a granular carbon for this purpose in a column process would be economical or that the carbon could be reactivated for re-use. The possibility existed that the more refractory organic materials exemplified by the sodium salts of the alkylbenzenesulfonates (ABS) would form inorganic residues during thermal reactivation that would interfere with the adsorptive properties of the carbon in subsequent cycles.

The current study was initiated to estimate the optimum bed depth and flow rates necessary for most economical use of the adsorptive properties of the carbon and to examine the feasibility of regenerating the carbon for re-use by thermal reactivation or an alternative procedure. Because elimination of the concentration and composition variables encountered in a real waste-water effluent was desirable, and because ABS was believed to be typical of the refractory organic materials likely to interfere with the regeneration of the spent carbon, a solution of ABS in water was selected as the effluent for the first phase of the program. In the second phase a column test was made on the effluent from a secondary-treatment plant.

SUMMARY

Granular, activated carbon used in a continuous-column process has demonstrated an ability to reduce the ABS content of aqueous solutions to negligible amounts. Virgin carbon removed ABS from a 10 ppm solution to a 0.5 ppm breakpoint, at a dosage of 0.5 pound per 1,000 gallons, at a flow rate of 2.5 gallons per minute per square foot of cross-sectional bed area. Tests at higher flow rates indicate that the carbon dosage is primarily a function of residence time and that a dosage of 0.5 pound per 1,000 gallons can be obtained at flow rates as high as 10 gallons per minute (gpm) per square foot provided that sufficiently deep beds are used.

Treatment of secondary effluent, containing approximately 50 ppm COD and 5 ppm ABS, with granular, activated carbon in a countercurrent-column process produced effluents having COD values of from 12 to 20 ppm and ABS concentrations well under 0.5 ppm. It is estimated that for this treatment the amount of carbon regenerated would be less than 1 pound per 1,000 gallons. If the unadsorbed COD is attributable to organic matter in solution, increased residence time might effect more complete removal.

If it is assumed that COD can be reduced to 5 ppm by increasing the column residence time and that the average adsorption capacity of the carbon will be 50 percent of its virgin capacity, overall treatment costs to accomplish this degree of purification are conservatively estimated to be in the range of $0.06 to $0.08 per 1,000 gallons of secondary effluent.

Analysis of granular, activated carbon before and after its saturation by the adsorption of ABS from a tap water solution showed that the adsorbed ABS was present predominantly as the calcium salt. In accelerated batch reactivation tests, granular carbon was alternately loaded with Ca-ABS and thermally reactivated for 10 complete cycles. At the completion of the test the ash content of the carbon had doubled, the added ash being insoluble in water but soluble in acid. Further, after 10 cycles the capacity of the carbon for the adsorption of ABS from a dilute solution was approximately half of the virgin capacity. Preliminary tests indicate that if it is necessary to prevent this ash buildup in practice, it can probably be done by treatment of the carbon, after thermal reactivation, with acid or preferably a less corrosive reagent for the solution of calcium salts. Elimination of the insoluble ash buildup by conversion of the adsorbed Ca-ABS to the free acid or sodium salt prior to

thermal reactivation is not considered feasible since it appears impractical to obtain more than a 60 percent conversion.

Thermal reactivation of granular carbon, following its use for the treatment of secondary effluent, restored its virgin adsorptive properties despite a 6 to 9 percent increase in the total ash content. The alkylbenzenesulfonates represent only a fraction of the total organic materials in secondary effluent and hence only a fraction of the total organic material on the spent carbon. As a consequence the buildup of insoluble ash should in practice be markedly less than that obtained in the accelerated test wherein ABS was the only adsorbate. For this reason it is concluded that cyclic reactivation tests in which the carbon is exhausted by contact with real waste-water effluent are required before consideration is given to pre- or post-reactivation treatments.

RECOMMENDATIONS

The following recommendations are made for future work on this program:

1. That additional laboratory studies be made to obtain preliminary information on the unadsorbed fraction of the COD as well as determine the feasibility of adsorbing the COD residual on activated carbon;

2. that column studies on a real effluent be conducted at higher residence times than those used in the initial tests, if the COD residual is caused completely or in part by dissolved organic matter, to determine the effects of this variable on COD removal;

3. that cyclic regeneration tests be performed in which granular carbon is alternately exhausted with real effluent and thermally reactivated to determine the extent of insoluble ash buildup and its effects on the operating capacity of the carbon;

4. that column tests be made to define more accurately the rate at which the inlet end of the carbon bed becomes saturated with the organic matter in secondary effluent to permit the design of adsorbers that will ensure maximum utilization of the adsorptive capacity of the carbon;

5. that the effects of suspended solids on the adsorptive capacity of the carbon and on the pressure drop in column operation be examined to determine whether prefiltration of the secondary effluent is necessary;

6. that engineering studies directed towards the selection of the most economically practical types of adsorber for this operation, and the design of a pilot plant be initiated as soon as possible so that current bench scale studies can be utilized to obtain the data necessary for the optimum design; the pilot plant design should be sufficiently flexible to permit the evaluation of the types of adsorber that are not ruled out economically.

EXPERIMENTAL APPROACH

Materials

ACTIVATED CARBONS

Three samples of Pittsburgh granular carbon, selected to cover the range of adsorptive capacities in commercial liquid-phase carbons, were used in this investigation.

ALKYLBENZENESULFONATE

A sample of standard ABS obtained from the Association of American Soap and Glycerine Producers Incorporated was used for all the tests.

Isotherm Tests

APPARATUS

Spex Mixer Mill, equipped with steel vial and steel balls;
Burrell "Wrist-Action" Shaker;
Erlenmeyer Flasks, stoppered, 500 and 1,500 milliliters;
Büchner funnels and filter flasks;
Whatman No. 3 filter paper;
Analytical and semi-micro balances.

PROCEDURE

The granular carbons selected for testing were pulverized to a 95 percent, 325-mesh size in the Spex mill. Various weights of the pulverized carbon, between 10 and 200 milligrams, were added to either 500- or 1,500-milliliter volumes of ABS solution in Erlenmeyer flasks. The stoppered flasks were mounted on the shaker and agitated for 2 hours. The contents of the flasks were then filtered, and the ABS content of the filtrate was determined. A preliminary rate test in which 100 milligrams of pulverized carbon was agitated with a 50 ppm solution of ABS for 0.5, 1, 2, and 4 hours showed that the amount of ABS adsorbed after 2 hours was equal, within the limits of experimental error, to that adsorbed after 4 hours. The ABS solutions used had initial concentrations ranging from 1.3 to 54.9 ppm.

For each isotherm, "blank" determinations were made in which ABS solution without carbon was subjected to the same filtration procedure as the samples containing carbon. The net weight of ABS adsorbed (x) for each sample was determined by subtracting the filtrate concentration from the appropriate "blank" filtrate concentration. This value was divided by the weight of carbon used in the test to determine the weight adsorbed per gram of carbon (x/m). The amount adsorbed (x/m) was plotted as ordinate, and residual filtrate concentration (c), as abscissa, on log-log graph paper, and the best straight line was drawn through the points.

Column Tests On ABS Solution

APPARATUS

The columns consisted of 1-inch-diameter pyrex pipe sections. Pyrex pipe reducers, 1 by 3/8 inch, were flange connected to the top and bottom of each section. A piece of 50-mesh stainless steel screen was held by gaskets in the lower flange of each section to support the carbon bed. Connections were made between the columns and from the pumps to the columns with polyethylene tubing attached to the pyrex pipe tubing, which, in turn, was attached to the pyrex pipe connections by Sentinel "quick-disconnect" couplings.

The 10 ppm ABS solution used for these tests was prepared in a 200-gallon tank and fed to the columns by means of Zenith laboratory, metering, gear pumps.

Three types of carbon were used in the tests with ABS solutions. These are designated as types A, B, and C in the report. The commercial designations of these carbons are: A, Pittsburgh Chemical Co. Type CAL; B, Pittsburgh Chemical Co. Type SGL; and C, Pittsburgh Chemical Compar Type MWT.

Three flow rates were investigated, 2.5, 5.0, and 10.0 gpm per square foot of cross-sectional bed area. The bed depths used ranged from 2.5 to 15 feet. Either 3-foot columns containing 170 grams of carbon to give a 2.5-foot bed depth, or 6-foot columns containing 340 grams of carbon to give a 5.0-foot bed depth were connected in series for downflow operation. Sampling ports were installed after each column section.

Figure 1 is a drawing of the apparatus, showing the column arrangement used at 5.0 gpm per square foot.

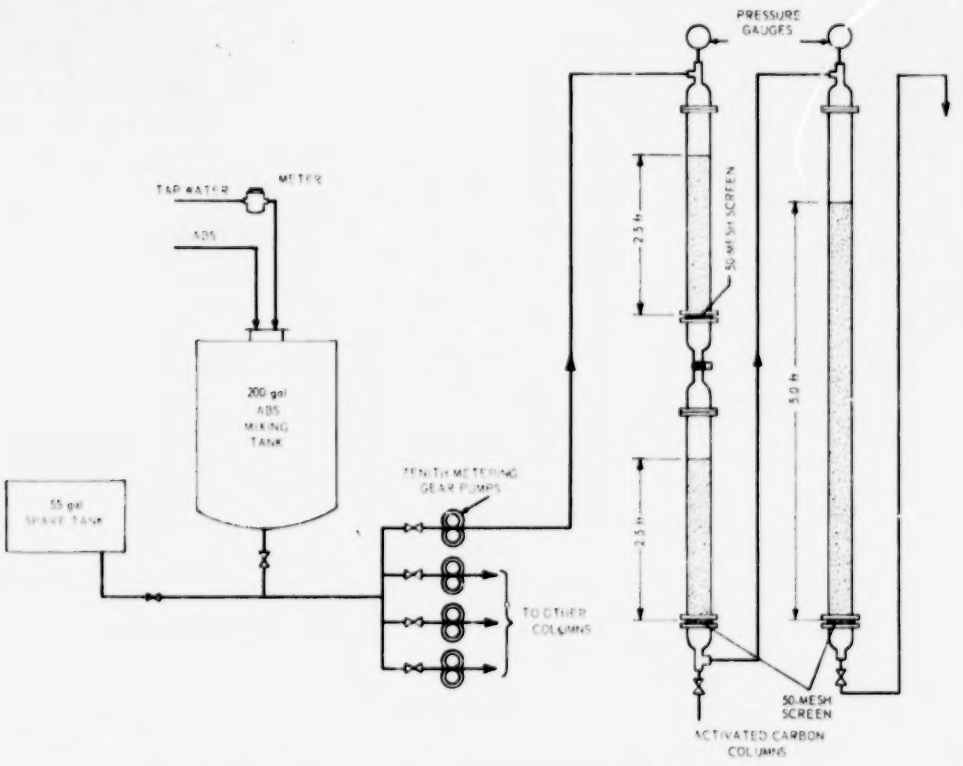

Figure 1. Apparatus for column tests on ABS solution. Column arrangement for tests at 5 gpm/ft^2.

PROCEDURE

Sufficient carbon to fill one column section was degassed by boiling in water for 10 minutes. The slurry was spooned into the column, which was partially filled with water, at such a rate that the carbon level never rose above the water level.

A 10 ppm solution of ABS in tap water was prepared in the mixing tank. This solution was pumped to the columns at the desired rates by means of the metering pumps. Breakthrough curves were established at each flow rate by collecting samples from each column section at intervals and determining the ABS content. The ABS content of each batch of influent prepared was also determined.

Column Tests On Secondary Effluent

PLEASANT HILLS TREATMENT PLANT

The Pleasant Hills Waste-water Treatment Plant in suburban Pittsburgh was selected as the site for the column tests. This is a well-designed and efficiently operated plant that has been in operation since 1959 and employs activated-sludge secondary treatment. An area with a population of 17,000 is serviced. The influent is almost completely domestic waste water; the only exceptions are the wastes from several laundromats in the area.

The plant is designed for an average flow capacity of 3.0 mgd and a maximum flow of 4.5 mgd. Normally the average flow is approximately half of the design figure. During the test period, however, which extended from mid-February to mid-April, considerable wet weather was encountered and the average flow during this time was 2.8 mgd. During this period the 5-day BOD values averaged 147 ppm in the influent and 7 ppm in the final effluent, corresponding to an average reduction of 95 percent. Suspended solids averaged 148 ppm in the raw waste water and 20 ppm in the final effluent for an average overall reduction of 87 percent.

A flow sheet and a brief description of the operation of the Pleasant Hills Plant are given in Appendix A.

APPARATUS

Figure 2 is a photograph of the apparatus.

The columns were filled with Pittsburgh Chemical Company commercial carbon designated as Type SGL. Each column consisted of a 6-foot section of 2-inch-inner-diameter pyrex pipe. Pyrex pipe reducers, 2 by 3/8 inch, were flange connected to the top and bottom of each pipe section. A 50-mesh stainless

steel screen was inserted in the bottom flange to support the carbon bed. Four such sections were connected in series for downflow operation. A pressure gauge was mounted at the top and a sampling port was installed at the bottom of each column section. Each column contained 1, 360 grams of granular carbon, which provided a bed depth of 5 feet per section and an overall bed depth of 20 feet.

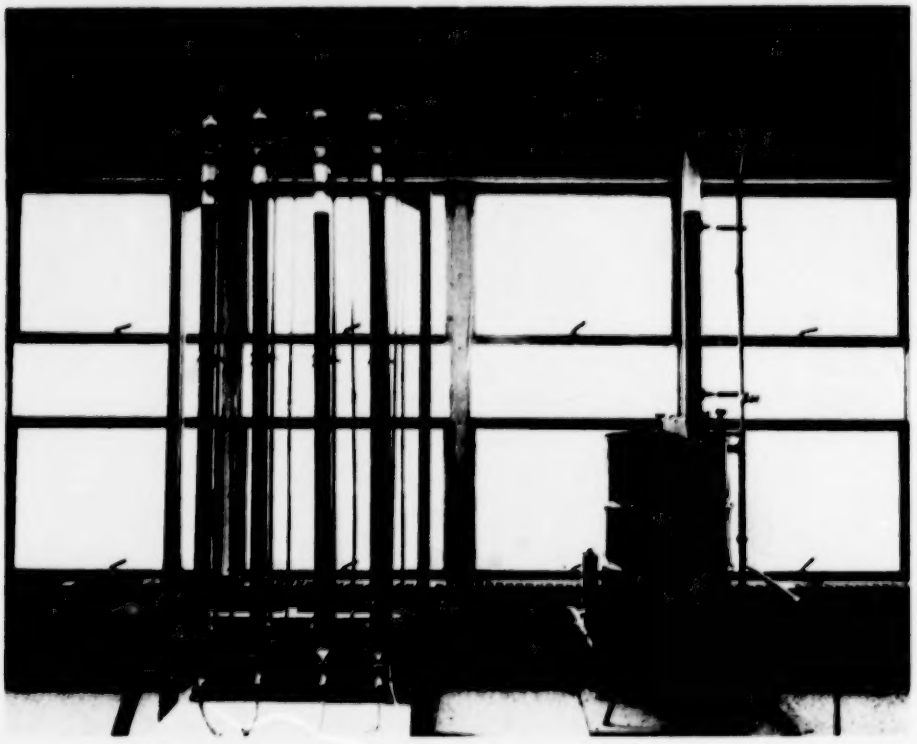

Figure 2. Apparatus for column tests on secondary waste-water effluent.

Final effluent, before chlorination, was withdrawn continuously from the main line supplying the spray water to the aeration tanks through a 3/4-inch pipe installed between the main line and the reservoir feeding the column system. The final effluent was passed through a 3-foot-deep, graded-sand filter, housed in a 4-inch-diameter pyrex pipe, into a 55-gallon drum, fitted with an overflow pipe. The sand filter was piped so that it could be backwashed at intervals with final effluent.

Filtered effluent was pumped from the 55-gallon drum at a flow rate of 10 gpm per square foot by means of a Zenith laboratory, metering, gear pump. Connections from the reservoir to the pumps, from the pump to the first column, and from column to column were made with copper tubing.

PROCEDURE

Granular carbon was charged to the columns by the procedure outlined above for the column tests on ABS solution. Filtered effluent was pumped to the columns at a flow rate of 10 gpm per square foot. Effluent samples were collected from each column section at intervals and analyzed for ABS and COD. Simultaneously samples were collected from the reservoir for the same analyses. Initially volatile-solids determinations were made, but this practice was discontinued because of the erratic results obtained.

At the start of the test program grab samples of the column influent and effluent were collected. Later the sampling procedure was modified and 24-hour-composite samples were collected.

The test was continued until the effluent from the fourth column showed an ABS content of 0.5 ppm. At this point the system was shut down. The carbon in the first column was removed and thermally reactivated by the procedure outlined below. The reactivated carbon was recharged to the empty column and this column was installed in the number four or final position in the series.

When the ABS content of the effluent from the fourth column again reached 0.5 ppm, the carbon in the original number two column, which had occupied the first position in the second cycle, was reactivated, recharged, and returned to service in the number four position. The test was terminated when the third cycle was completed, that is, when a 0.5 ppm ABS breakthrough was obtained from the fourth column.

Reactivation Tests

BATCH CYCLIC REACTIVATION TESTS

A 500-gram sample of granular carbon was immersed in 4.5 gallons of a 7,000 ppm solution of Na-ABS in a 5-gallon bottle. The bottle was agitated intermittently for 6 hours. After the liquid was decanted from the bottle the carbon was washed out, filtered, and rinsed thoroughly with water. The carbon was then immersed in 4.5 gallons of 3,400 ppm calcium chloride in a second 5-gallon bottle, which was also agitated intermittently for 6 hours. The calcium chloride solution was then decanted from the bottle, and the carbon was washed out, filtered, and rinsed thoroughly with water.

The dried, spent carbon was thermally reactivated in 100-gram batches in the laboratory weighing furnace (Figure 3). The furnace was preheated to 1, 700°F and 100 grams of carbon was transferred to the nichrome basket. The basket was placed in the hot zone of the furnace and suspended from the balance arm. An atmosphere of natural gas, air, and steam was passed through the furnace. The reactivation was continued until the original apparent density was restored.

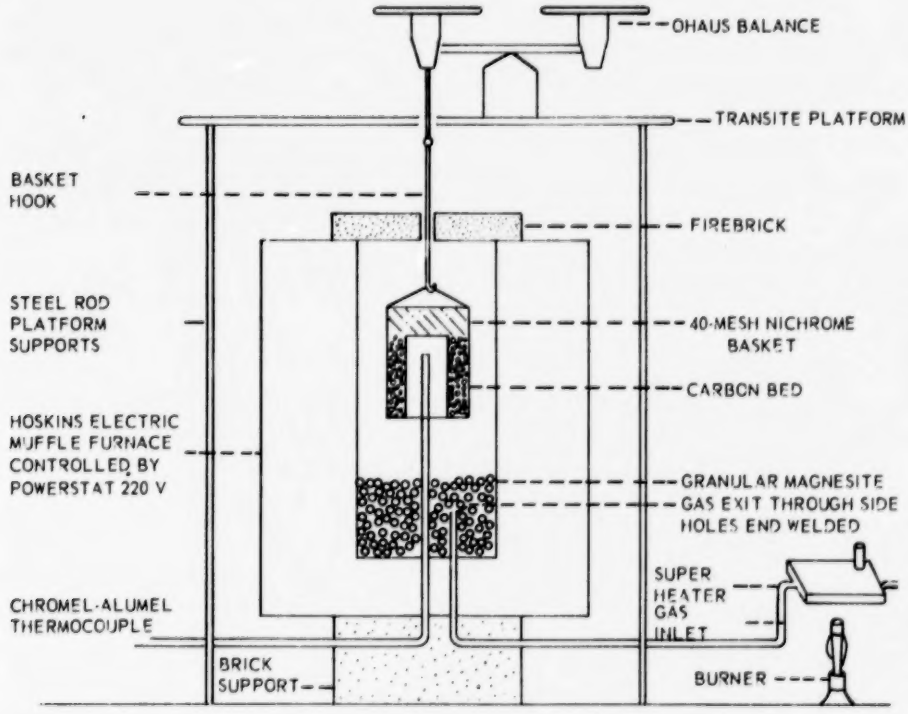

Figure 3. Laboratory weighing activator.

This procedure of alternate saturation with Ca-ABS and thermal reactivation was repeated for a total of 10 complete cycles. The molasses and iodine activity of the reactivated carbon was determined at intervals. In later cycles the reactivation time was increased to obtain apparent densities lower than those of the virgin carbon in an attempt to maintain the activity of the carbon at a satisfactory level.

REACTIVATION OF SPENT CARBON FROM WASTE-WATER EFFLUENT TESTS

Spent carbon from the waste-water effluent tests was reactivated in a pilot plant rotary furnace,* which has a capacity of approximately 1 gallon of carbon. A temperature of 1,700°F and an atmosphere consisting of 34 percent by volume steam and 66 percent by volume air was used. Under these conditions the carbon was restored to essentially virgin activity at a retention time of 14 minutes. Standard activity tests were made before and after reactivation.

REACTIVATION TESTS WITH STEAM AT RELATIVELY LOWER TEMPERATURES

A sample of spent carbon from the column tests on ABS solution was refluxed with twice its volume of 5 percent hydrochloric acid, thoroughly rinsed with water, and dried.

A 100-gram portion of the dried sample was transferred to a nichrome basket and placed in a muffle furnace preheated to 950°F. Steam was passed through the furnace at a rate of 3 grams per minute. At intervals the basket was removed from the furnace and weighed. The reactivation was continued until an apparently constant weight was obtained.

This procedure was repeated with a second 100-gram portion of the acid-treated carbon and a furnace temperature of 650°F. Standard activity values were obtained on the carbon before and after reactivation.

CONVERSION OF ADSORBED ABS TO FREE ACID OR SODIUM SALT

1. The spent carbon from the first-column section used for the treatment of a 10 ppm solution of ABS at 2.5 gpm per square foot was thoroughly rinsed and oven dried. The calcium, magnesium, and sodium contents of the carbon were determined.

2. A 60-gram portion of the spent carbon was charged in water to a percolation column, 1.25-inch inner diameter, 10 inches long, with a 5-millimeter-inner-diameter

* American Gas Furnace Company Rotary Gas Carburizer, Type No. 1-F, modified in our pilot plant.

bottom outlet, fabricated of pyrex tubing. This quantity of carbon was sufficient to give a bed depth between 6 and 7 inches. The carbon bed was supported by a glass wool plug.

3. One liter of 5 percent hydrochloric acid was percolated through the bed at a flow rate of 26 milliliters per minute. This flow rate corresponded to the same contact time that would be obtained at 5 gpm per square foot in a 3-foot bed. The effluent was collected in 100-milliliter fractions, and the calcium and magnesium contents of each fraction were determined.

4. After 1 liter of effluent was collected, 1 liter of tap water was passed through the bed at the same flow rate. The effluent was collected in 100-milliliter fractions, and the calcium and magnesium contents were determined.

5. Steps 2 and 3 were repeated with a 5 percent sodium chloride solution instead of the 5 percent hydrochloric acid solution.

Corrosion Test

A test coupon (7.69 cm x 2.93 cm x 0.073 cm) was cut from a sheet of mild steel. The coupon was sand blasted; washed in turn with dilute hydrochloric acid, water, and acetone; dried; and accurately weighed. The strip was imbedded in the fourth carbon column at the treatment plant and left there for 31 days. At the end of this period the coupon was removed, soaked in boiling ammoniacal ammonium citrate solution, washed in turn with water and acetone, dried, and reweighed.

Analytical Methods

EFFLUENT ANALYSES

ABS	Methylene blue method*
COD	Dichromate method† (all COD values given are chloride corrected)
Chlorides	Potentiometric method‡
Volatile solids	Total volatile and fixed residue§
Calcium	EDTA titration
Magnesium	EDTA titration

CARBON ANALYSES

Apparent density	PCC method//
Ash	PCC method#
Iodine number	PCC method**
Molasses number	PCC method††
Calcium	EDTA titration after ashing and fusion
Magnesium	EDTA titration after ashing and fusion
Sodium	Flame photometry

RESULTS AND DISCUSSION

Isotherm Tests

A typical isotherm plot is shown in Figure 4. The isotherm has been extrapolated to intersect a vertical line originating at C_o, the initial concentration. The point of intersection $(x/m)_{Co}$ should represent the capacity of the carbon for ABS when that

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* Standard Methods for the Examination of Water and Waste Water, Eleventh Edition, pp. 245 - 248.

† Ibid, pp. 399 - 402.

‡ Ibid, pp. 279 - 282.

§ Ibid, p. 327.

// Test Methods of the Carbon Plant Control Laboratory, Pittsburgh Chemical Company, 1960, Test No. 4.

Ibid, Test No. 7.

** Ibid, Test No. 14.

†† Ibid, Test No. 15.

carbon is in equilibrium with a solution of concentration C_O. This equilibrium should be attained in at least the first section of a granular carbon bed through which a solution of C_O concentration is being percolated. Theoretical adsorptive capacities obtained in this manner are summarized in Table 1 for the various ABS concentrations and the three carbons tested.

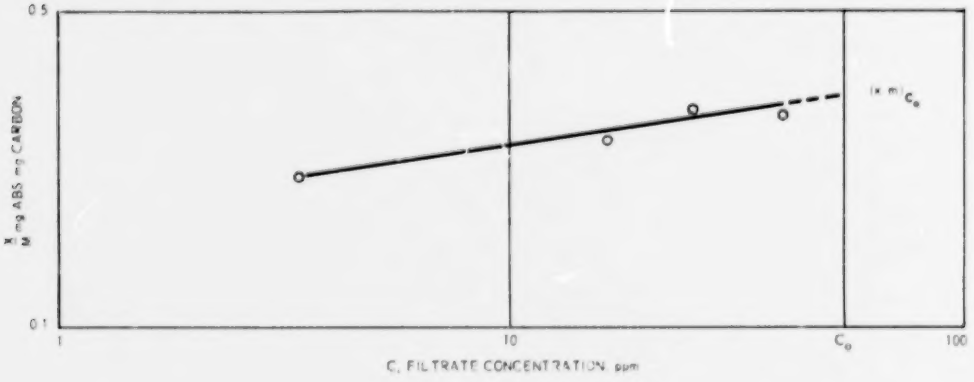

Figure 4. ABS adsorption isotherm, carbon sample B.

Carbon A and Carbon B are both high-capacity, liquid-phase carbons. They have essentially the same surface area but differ in that Carbon A has a larger fraction of its surface area in pores in the 20 to 50 Angstrom range. It is apparent that at both the 54.9 and 11.6 ppm initial ABS concentrations the

Table 1. ADSORPTION CAPACITIES $\left(\left[\frac{X}{M}\right]_{C_o}\right)$: ACTIVATED CARBONS FOR ABS

Carbon sample	Initial ABS concentration, ppm	$\left(\frac{X}{M}\right)_{C_o}$ g ABS/100 g C
A	54.9	28
B	54.9	32
C	54.9	18
A	11.6	22
B	11.6	21
B	2.0	15
B	1.3	13

two carbons have essentially the same capacity for ABS. Carbon C has a smaller surface area than A or B and an obviously smaller ABS capacity. It was concluded that the surface area of the carbon was the prime consideration for ABS adsorption, and

Carbon B was used for all the column tests. Preliminary tests indicated that efficient ABS adsorption could be achieved at comparatively high flow rates, and so a relatively large-mesh-size carbon, 8 x 30, was chosen for the column tests to minimize pressure drop.

Column Tests On ABS Solution

Breakthrough curves at the three flow rates investigated are shown in Figure 5.

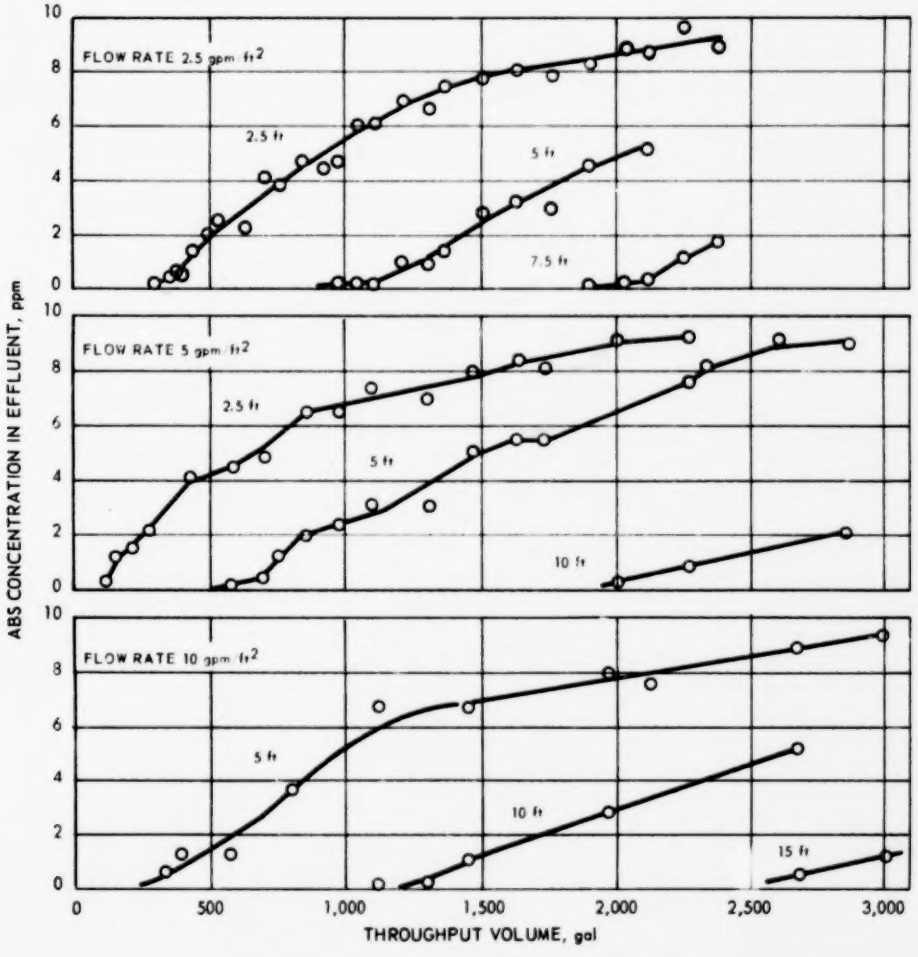

Figure 5. Breakthrough curves for the removal of ABS from a 10 ppm aqueous solution.

The effects of increasing bed depth are apparent from the first set of curves at a 2.5 gpm per square foot flow rate, where

three 2.5-foot beds were connected in series. To compare the performance of the columns a breakpoint of 0.5 ppm ABS was selected. At 2.5 gpm per square foot less than 400 gallons were collected from the first 2.5-foot section before the breakpoint was reached, whereas approximately 1,200 and 2,200 gallons were collected from the second and third sections respectively. The same general trend of a marked increase in volume of acceptable effluent with increasing bed depth can be observed in the breakthrough curves at the other flow rates shown in Figure 5. If, at any flow rate, the total bed depth had been increased by the addition of 2.5- or 5.0-foot bed sections, a point would have been reached where the volume of acceptable effluent would increase linearly with bed depth. In the case of a dilute solution such as this, however, a prohibitively long time would be required to establish that point.

The data calculated from the breakthrough curves have been summarized in Table 2. At each flow rate and bed depth the throughput volume to a 0.5 ppm breakpoint is listed. The weight of ABS adsorbed per unit weight of carbon was determined by graphical integration of the breakthrough curves. From the throughput volume and the weight of carbon in each column the

Table 2. COLUMN CAPACITY DATA FOR THE ADSORPTION OF ABS FROM A 10 ppm AQUEOUS SOLUTION

Flow rate, gpm/ft^2	Bed depth, ft	Capacity to 0.5 ppm breakpoint: Throughput vol, gal	Capacity to 0.5 ppm breakpoint: ABS adsorbed, g/100 g C	Total ABS adsorbed,[a] g/100 g C	Carbon dosage, lb/1,000 gal
2.5	2.5	363	8.9	24.0	0.97
	5.0	1,216	14.3	20.5	0.62
	7.5	2,148	15.9	15.9	0.53
5.0	2.5	141	3.1	19.7	2.66
	5.0	730	8.1	17.7	1.03
	10.0	2,190	12.7	12.7	0.69
10.0	5.0	332	3.7	14.3	2.22
	10.0	1,380	7.7	12.8	1.09
	15.0	2,760	10.4	10.4	0.82

[a] To 0.5 ppm breakpoint from third-column section.

carbon dosage in terms of pounds per 1,000 gallons of 10 ppm solution was calculated. The total ABS adsorbed at each bed depth was also obtained by graphical integration of the breakthrough curves, and represents in each case the amount of ABS adsorbed by the first section, by the first and second sections combined, and by the three sections combined when the effluent concentration from the third section reached 0.5 ppm.

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It is evident from Table 2 that, at gpm-per-square-foot rates of 2.5 in a 2.5-foot bed, of 5.0 in a 5.0-foot bed, and of 10 in a 10-foot bed, the carbon dosage is approximately 1 pound per 1,000 gallons. The contact time in each case is the same. It seems reasonable to conclude that at 5.0 gpm per square foot in a 15-foot bed and at 10 gpm per square foot in a 30-foot bed, the contact time and therefore the carbon dosage will be the same as that obtained at 2.5 gpm per square foot in a 7.5-foot bed, that is, 0.5 pound per 1,000 gallons.

Note that after breakthrough occurs from any column section the carbon in that section still has considerable capacity for ABS adsorption. This is particularly evident from the total-ABS-adsorbed amounts in Table 2. At 2.5 gpm per square foot, for example, the first 2.5 feet of bed adsorbed 24 percent by weight ABS and the first 5.0 feet of bed adsorbed 20.5 percent by weight ABS when breakthrough occurred from a 7.5-foot bed depth.

This observation suggests that maximum utilization of adsorptive capacity of the carbon can be effected by operating a series of short beds countercurrently. For example, at 2.5 gpm per square foot the first 2.5-foot bed could be removed from service when the effluent from the third section reached the breakpoint and replaced with a fresh bed in the number 3 position.

Carrying out this procedure indefinitely would ensure that only highly saturated carbon would be reactivated. At the higher flow rates a series of deeper bed sections would be necessary.

The maximum capacities obtained in the column tests, from 20 to 24 percent by weight ABS, are in reasonable agreement with the 22 percent by weight figure obtained in the isotherm tests for an initial ABS concentration of approximately 10 ppm.

Column Tests On Secondary Waste-Water Effluent

The analytical data accumulated during the plant tests are listed in Table 3. ABS and COD breakthrough curves for the fourth column, that is, for a total bed depth of 20 feet, are plotted in Figure 6. Curves for the intermediate bed depths have been omitted to simplify the diagram. The open points connected by dashed lines represent grab samples. The solid points connected by solid lines represent 24-hour-composite samples. Throughput volumes, averages of the influent and effluent analyses, and carbon dosages for the three cycles are summarized in Table 4. Included are averages of the total flow and the analytical data from the waste-water plant for the corresponding period.

Table 3. ANALYTICAL DATA: COLUMN TESTS ON SECONDARY EFFLUENT

			ABS, ppm					COD, ppm					Volatile solids, ppm				
				Column No.					(chloride corrected) Column No.					Column No.			
Date	Time	Throughput, gal	Influent	1	2	3	4	Influent	1	2	3	4	Influent	1	2	3	4
2-13	700	254	8.6	1.7	0.3	0.3	0.2	115.7	81.9	63.7	59.7	56.8	130	125	69	73	106
2-14	900	581	7.3	3.0	0.6	0.2	0.1	82.2	57.6	44.7	38.9	41.5	152	73	85	73	76
2-15	715	863	6.0	3.0	0.6	0.1	0.1	90.6	92.0	60.2	35.6	26.8	130	97	121	88	110
2-16	715	1,166	6.2	3.5	1.0	0.2	0.1	65.8	42.8	34.0	31.4	17.7	122	91	68	73	83
2-19	850	2,038	5.7	3.5	1.1	0.2	0.1	49.2	36.1	23.7	16.1	20.3	118	89	87	95	84
2-21	800	2,550	5.3	3.0	1.4	0.3	0.1	62.0	37.3	29.2	24.1	22.1	97	93	84	57	58
2-23	700	3,132	4.9	3.7	2.2	1.0	0.3	61.2	56.5	31.2	27.6	25.1	138	106	110	110	107
2-26	645	3,904	4.0	2.0	1.6	0.7	0.2	54.7	33.2	28.7	16.9	9.2	119	95	93	87	77
2-28	730	4,430	2.8	1.9	1.2	0.6	0.2	43.6	42.9	20.8	24.6	22.2	80	57	71	66	72
3-2	700	5,008	4.5	2.9	2.0	1.0	0.4	109.1	42.9	28.1	22.7	18.9	145	82	87	57	78
3-5	700	5,880	4.9	3.7	2.8	1.6	0.6	51.5	34.5	26.3	16.1	13.5	110	105	98	88	94
3-9	700	6,220	5.2	2.8	1.6	0.5	0	70.7	47.0	26.4	16.2	9.0	56	54	56	48	36
3-12	700	6,893	3.6	2.2	1.6	0.8	0.1	36.5	13.4	16.3	8.2	12.2	96	83	74	76	75
3-14	700	7,470	3.0	1.8	1.2	0.5	0.1	89.6	41.1	23.6	10.0	3.2	129	106	91	92	93
3-16	730	8,041	3.7	2.7	2.1	1.0	0.2	52.0	40.8	27.6	25.5	17.2					
3-18	700	8,650															
3-19	700	8,928	5.5	4.1	2.9	1.8	0.3	36.0	28.9	24.2	18.7	13.3					
3-20	700	9,243	7.1				0.5	42.7									
3-21	700	9,517	5.7	4.6	2.5	1.4	0.6	54.0	58.5	39.1	35.8	18.0					
3-23	1,330	9,517															
3-24	700	9,757	3.7					24.8									
3-25	700	10,053	4.2					18.3									
3-26	700	10,364	4.3				0.1	58.3				21.2					
3-27	700	10,638	4.6	3.3	2.3	0.9			34.3	20.3	14.2						
3-28	700	10,924	6.0				0.2	63.7									
3-29	700	11,183	6.1	4.2	2.3	0.5		44.3	42.2	24.1	15.2						
3-30	700	11,442	6.3				0.1	41.7				9.7					
3-31	700	11,686	6.1	4.9	3.2	1.1		40.4	28.9	16.3	21.9						
4-1	700	11,926	4.7					33.7									
4-2	700	12,287	3.4					39.0				9.7					
4-3	700	12,526	3.4	2.1	1.6	0.8	0.2	34.1	16.4	30.3	9.8	3.0					
4-4	700	12,850	4.5				0.3	23.9				0.8					
4-5	700	13,117	4.4	3.4	2.6	1.3	0.2	33.3	40.4	17.3	41.5	23.7					
4-6	700	13,398	4.7				0.4	36.9				13.1					
4-7	700	13,666	5.0	3.9	3.0	1.5	0.5	22.6	25.5	21.9	15.5	15.2					
4-8	700	13,926	3.9				0.4	23.0				25.7					
4-9	700	14,100	3.4	1.7	1.1	0.6	0.3	25.1	20.7	20.0	14.3	18.7					

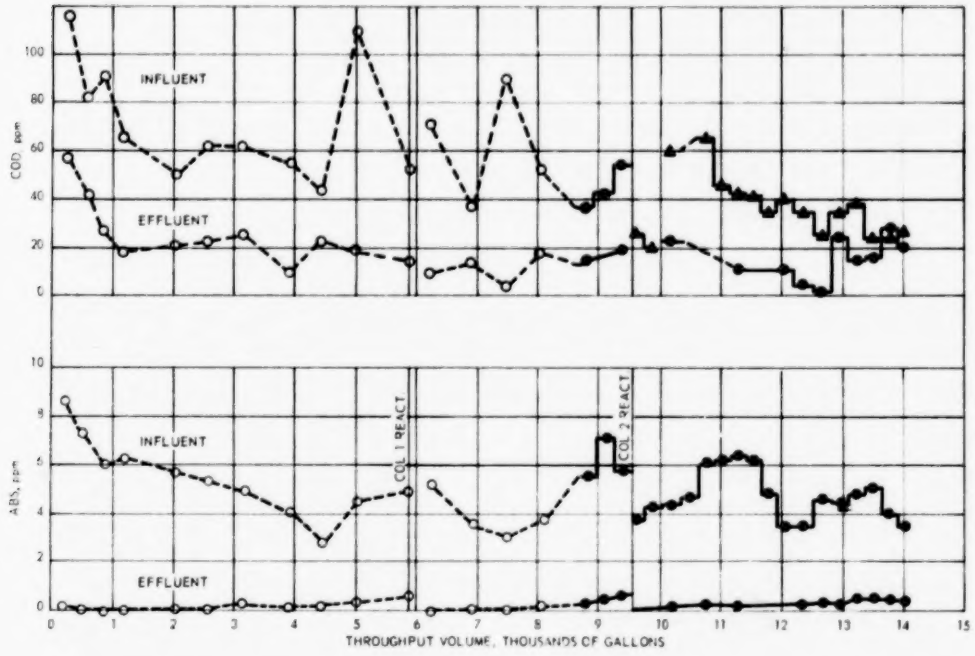

Figure 6. Breakthrough curves for column tests on secondary waste-water effluent.

Table 4. SUMMARY OF DATA: COLUMN TESTS ON SECONDARY EFFLUENT AT 10 gpm/ft^2

	Cycle 1	Cycle 2	Cycle 3
Column data			
Throughput, gal	5,880	3,627	4,583
Avg COD content, ppm			
Influent	70	55	35
Effluent	20	12	14
Avg ABS content, ppm			
Influent	5.5	4.8	4.6
Effluent	0.2	0.3	0.2
Carbon dosage,[a] lb/1,000 gal	0.50	0.83	0.66
Plant data			
Avg flow, mgd	2.44	3.03	3.24
Avg BOD, ppm			
Raw	154	103	141
Final	7	5	7
Avg suspended solids, ppm			
Raw	175	126	135
Final	21	20	19

[a] Based on carbon change in one column.

It is apparent from Figure 6 and Table 4 that the material contributing to the COD was not completely removed by the activated carbon. A residual of from 12 to 20 ppm remained in the effluent. No attempt was made to determine the nature of this residual COD.

Note that to expedite the program a flow rate of 10 gpm per square foot was selected. This is an unusually high flow rate for granular carbon columns. It is possible that increasing the contact time by using deeper beds or lower flow rates would effect better COD removal. The possibility that part of the residual COD may arise from a colloidal dispersion of carbon fines, from the sloughing off of algae or bacterial growths, or from an inorganic contaminant has not been precluded. Obviously more experimental work is necessary in this area.

It is also obvious that the average influent COD during the third cycle (35 ppm) was markedly lower than during the first and second cycles (70 and 55 ppm respectively). The reason for this variation is not immediately apparent. The average total flow through the waste-water treatment plant was highest during the third cycle. Since this increased flow is attributed to the infiltration of water from storm-water drains in the older part of the system, a dilution effect would be expected. The dilution cannot, however, account for all of the COD reduction. It is possible that the average COD values for the first and second cycles are unrealistically high since they are based on spot samples and since 24-hour-composite samples were collected during the third cycle. The spot samples were, however, collected at 7 a. m., and one would not expect peak values at this time. The ABS content of the secondary effluent appears to be more uniform than the COD content.

Carbon dosages calculated from these data yield values of 0. 50, 0. 83, and 0. 66 pound of carbon regenerated per thousand gallons of waste-water effluent treated. These amounts are preliminary. To determine an exact amount it would be necessary to continue the cyclic tests until equilibrium was established. This would involve a prohibitive period of time for a preliminary investigation. It appears, however, that the dosage can be conservatively estimated at less than 1 pound carbon per 1, 000 gallons for this particular effluent.

On two occasions during the last cycle, 5-day BOD values were obtained on grab samples of the influent and effluent of the column system. In one case the BOD was reduced from 16 to 6 ppm by the carbon and in the other from 4. 7 to 2. 8 ppm.

Economic Evaluation

ESTIMATION OF ACTIVATED CARBON REQUIREMENTS

It was shown above that for a secondary effluent containing approximately 50 ppm COD and 5 ppm ABS, the ABS can be readily reduced to less than 0. 5 ppm and the COD to the 12 to 20 ppm range in a column process. If it is assumed that increasing the residence time will effect increased COD removal, the data can be extrapolated to obtain an approximation of the contact time necessary for COD removal to a residual concentration of 5 ppm. This extrapolation was made, on the assumption that the fraction of the COD remaining in the effluent would decrease exponentially with increasing bed depth. A bed depth of 50 feet at 10 gpm per square foot was obtained, corresponding to a residence time, based on carbon volume, of 37 minutes.

The actual extent of saturation of the carbon with the organic materials that contribute to the COD is not known. To estimate this amount it was assumed that the same general pattern would be followed by COD as that found for ABS in the column tests on ABS solutions. For ABS data (Table 2), a plot of percent saturation of the carbon versus bed depth for residence times, based on column volumes of 15 and 22. 5 minutes showed maxima of 70 and 80 percent saturation respectively. It was estimated that a residence time of 37. 5 minutes would increase the maximum to approximately 90 percent saturation.

In the waste-water plant tests the cumulative carbon dosage after the third cycle was 0. 66 pound per 1, 000 gallons. It was noted above that this amount would no doubt increase after cyclic equilibrium was established. An amount of 1 pound per 1, 000 gallons is considered conservative. COD removal in the column tests at a residence time of 15 minutes, based on column volumes, ranged from 60 to 80 percent, and an estimated carbon saturation of 70 percent was effected. On the assumption of 100 percent COD removal at a residence time of 37 minutes and 90 percent saturation of the carbon, the dosage becomes, approximately, $1 \times 70/90 \times 100/60 = 1.3$ pounds per 1, 000 gallons.

It was also noted above that considerable doubt existed that the capacity of the carbon would decrease in practice as drastically as it did in the accelerated reactivation tests. For the sake of conservatism, however, it is assumed that the average capacity will be 50 percent of virgin capacity. The average dosage then becomes 2. 6 pounds per 1, 000 gallons. For a 10 mgd installation this amounts to 26, 000 pounds per day.

In relatively large installations for the thermal reactivation of granular carbon, overall reactivation losses range from 3 to 5 percent of the amount reactivated. This corresponds to activated-carbon makeup requirements of between 780 and 1,300 pounds per day at a cost of from $235 to $390.

The initial charge of granular carbon required for the treatment of 10 mgd of secondary effluent at a residence time of 37 minutes, based on column volume, amounts to 1 million pounds for treatment and an additional 200,000 pounds in process for a total of 1.2 million pounds and a cost of $360,000.

COST OF PLANT FACILITIES

Insufficient data are available at present to design a full-scale installation for the treatment of secondary waste-water effluent. The nature of the effluent and particularly the magnitude of the volumes involved are such that new concepts in adsorber design may have to be considered.

Based on existing knowledge, a flow sheet was prepared for a facility for the continuous activated-carbon treatment of 10 mgd of secondary waste-water effluent. A simplified flow sheet is shown in Figure 7. Arbitrarily, fixed-bed adsorbers piped for downflow operation were selected. In spite of the fact that this represents one of the simplest of the possible designs, it is estimated that the use of more complex adsorbers would not change the overall treatment cost significantly.

Reactivation equipment consisted of a Herreshoff furnace, spent- and reactivated-carbon storage tanks, and all the auxiliary equipment necessary for a complete hydraulic handling system for transfer of the spent carbon from the adsorbers to the furnace and of the reactivated carbon from the furnace to the adsorbers.

The process flow sheet was prepared in sufficient detail to show all the major materials-handling equipment. This equipment was selected to assure a system that was workable though not necessarily the most efficient. Instrumentation and control systems were selected to provide semiautomatic operation. The equipment was cost estimated to about the 30 percent certainty level, and to the subtotal of the individual items were added the estimated costs of site development, engineering, and a reserve for contingency. The overall totals amounted to $450,000 for a 10 mgd plant and $3,375,000 for a 100 mgd plant.

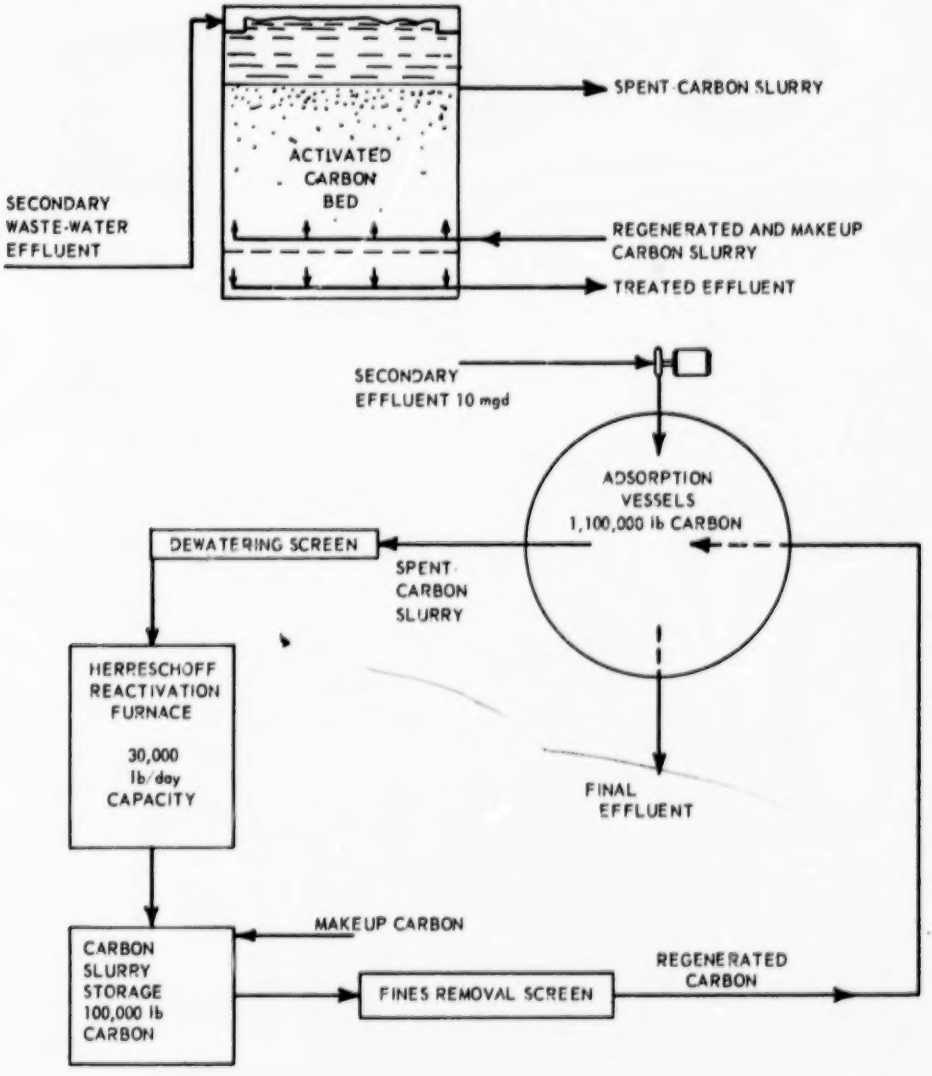

Figure 7. Simplified flow sheet for the removal of ABS and COD from 10 mgd of secondary waste-water effluent.

OVERALL TREATMENT COSTS

The overall treatment costs can be calculated from the above amounts and from appropriate estimates of the cost of labor and utilities. Daily costs for a 10 and a 100 mgd installation are summarized in Table 5. Per diem capital costs are based on a 20-year life and a 5 percent interest rate. It is estimated that operating and maintenance labor would average 4 man-hours per shift for a 10 mgd throughput and 8 man-hours per shift for a 100 mgd throughput.

Table 5. ESTIMATED COSTS FOR THE TREATMENT OF SECONDARY WASTE-WATER EFFLUENT[a]

Item	Cost, $/day	
	10 mgd	100 mgd
Capital investment		
Plant facilities	120	1,000
Initial carbon charge	100	1,000
Operating labor and maintenance	80	160
Utilities	125	1,000
Carbon makeup	235 to 390	2,350 to 3,900
Total	660 to 815	5,510 to 7,060
Treatment cost, $/1,000 gal	0.066 to 0.082	0.055 to 0.071

[a] A 20-year life and 5 percent interest are assumed.

Reactivation Tests

BATCH CYCLIC REACTIVATION TESTS

Comparison of the ash analyses of spent carbon from the column tests on aqueous ABS solution with those of the virgin carbon revealed that a small increase in the sodium content and a marked increase in the calcium content of the carbon occurred. It was reasoned that the sodium ions associated with the sulfonic acid groups of the ABS were exchanged for calcium ions in the water after adsorption. Since calcium ions were believed more likely than sodium ions to contribute to insoluble ash, it was considered desirable to carry out the accelerated tests with a carbon exhausted with Ca-ABS.

Preliminary tests indicated that batch treatment of the granular carbon with a 1,700 ppm solution of Na-ABS, followed by an aqueous rinse, effected a 17 percent increase in the oven-dry weight of the carbon. On the assumption of a molecular weight of 350 for the ABS salt, this corresponds to approximately 0.5 milliequivalents of ABS per gram of carbon. Subsequent batch treatment of the carbon with a 3,400 ppm $CaCl_2$ solution effected an increase in the calcium content amounting to 0.4 milliequivalents Ca per gram. From these observations it was concluded that the batch procedure would provide an accelerated method of loading the carbon with Ca-ABS.

Table 6 summarizes the results obtained in each cycle, while the properties of the virgin carbon and the carbon after the 10th reactivation are listed in Table 7.

Table 6. SUMMARY OF BATCH REACTIVATION TESTS

Cycle No.	Apparent density, g/cm³		ABS adsorbed,[a] % by wt	Activity	
	Spent	Reactivated		Molasses No.	Iodine No.
1	0.565	0.478	16.9	–	–
2	0.530	0.481	10.5	188	905
3	0.570	0.482	16.6	–	–
4	0.542	0.481	12.0	–	–
5	0.548	0.478	13.9	183	704
6	0.537	0.465	13.0	–	–
7	0.520	0.460	12.9	214	682
8	0.516	0.442	12.4	–	–
9	0.503	0.434	13.8	205	653
10	0.489	0.435	12.9	188	588

[a] Calculated from density difference.

Table 7. PROPERTIES OF ACTIVATED CARBON BEFORE AND AFTER BATCH REACTIVATION TESTS

Property	Virgin carbon	After 10 reactivations
Apparent density, g/cm³	0.480	0.435
Total ash, % by wt	5.30	11.90
Water-soluble ash, % by wt	0.03	0.02
Acid-soluble ash, % by wt	0.94	9.55
Ca, % by wt	0.08	2.05
Mg, % by wt	0.05	0.03
Na, % by wt	0.07	0.84
Molasses No.	195	188
Iodine No.	942	588

From Table 7 it is apparent that after 10 cycles the ash content of the carbon has doubled and there is a marked increase in the sodium and particularly the calcium contents. There is only a slight change in the molasses number, which correlates with the surface area contributed by pores greater than approximately 28 Angstroms in diameter. On the other hand there is a marked decrease in the iodine number, which correlates with the total surface area. From these observations we would conclude that the fine pore structure of the carbon is blocked.

The relatively high value (9.55%) of the acid-soluble ash of the carbon after 10 reactivations (Table 7) is surprising. Repeat analyses gave essentially the same result. This suggests that acid washing the carbon after thermal reactivation would eliminate the buildup of water-insoluble ash, and might increase the adsorptive capacity of the reactivated carbon. This phenomenon was not examined further in the current study, but will be investigated briefly early in the second phase of the program. In an isotherm test the carbon after 10 reactivations exhibited a total theoretical capacity of 8 percent by weight ABS for the adsorption of ABS from a 9 ppm solution compared with 20 percent by weight for virgin carbon.

These results must be interpreted with considerable caution. In the first place, an accelerated test of this kind has not been conducted before and there is no way of knowing how it compares with field performance. Second, the average amount of ABS adsorbed per cycle was 13.5 percent by weight of the carbon. In the waste-water plant tests the spent carbon that was regenerated had adsorbed approximately 4 percent by weight ABS. Accordingly, one would not expect in practice the rapid inorganic buildup encountered in the cyclic test. Further, it is anticipated that in practice 5 percent virgin carbon would be added each cycle for makeup. This would undoubtedly help maintain the quality of the adsorbent. In short, it is believed that cyclic regeneration tests in which the carbon is exhausted by contact with a real waste-water effluent must be conducted before the effects of ash buildup can be realistically evaluated.

REACTIVATION OF SPENT CARBON FROM WASTE-WATER PLANT TESTS

The properties of the spent and reactivated carbons from these tests are summarized in Table 8. In the sewage plant tests the spent carbon had adsorbed approximately 4 percent by weight ABS, a value estimated from the breakthrough curves in Figure 6, plus, of course, an undetermined quantity of the

organic materials that contribute to the COD. No difficulty was experienced in restoring this spent carbon to somewhat better than virgin activity, but a marked increase in ash content can again be observed. Although this increased ash is in itself not alarming since the same phenomenon occurs in many other granular carbon applications, its ultimate effect on the adsorptive capacity of the carbon cannot be estimated from a single reactivation.

Table 8. PROPERTIES OF SPENT AND REACTIVATED CARBON FROM WASTE-WATER PLANT TESTS

Property	Spent		Reactivated		Virgin
	Col 1	Col 2	Col 1	Col 2	
Apparent density, g/cm^3	0.525	0.528	0.484	0.483	0.480
Ash, % by wt	6.07	5.84	6.70	6.82	5.36
Molasses No.	182	203	200	196	195
Iodine No.	830	824	1,085	1,081	942

REACTIVATION TESTS WITH STEAM AT RELATIVELY LOWER TEMPERATURES

These tests were initiated to examine briefly the feasibility of regenerating the spent carbon in the adsorbers by acid treatment followed by steam regeneration. It was reasoned that conversion of the salt form of the adsorbed ABS to the free-acid form might make the adsorbate sufficiently unstable to permit a low-temperature regeneration.

Preliminary tests indicated that steaming alone was insufficient and that it was necessary to resort to steaming plus external heating to effect a reasonable degree of activation. The results of tests in which acid-treated carbon was steamed at temperatures of 650°F and 950°F are given in Table 9. At 650°F a prohibitively long time (288 min) was required to achieve a satisfactory degree of activation. The time was reduced to 70 minutes by increasing the temperature to 950°F though in this case the degree of reactivation was not satisfactory. For the same carbon, conventional thermal reactivation required from 15 to 20 minutes in the laboratory weighing furnace.

This line of investigation was not pursued further since it is believed that an acidproof adsorber equipped with an external heater to maintain the carbon at a temperature of from 650 to 950°F would be economically impractical.

Table 9. PROPERTIES OF ABS-SATURATED CARBON BEFORE AND AFTER ACID TREATMENT AND LOW-TEMPERATURE STEAM REACTIVATION

Property	Spent	Reactivated		Virgin
Furnace temp, °F	–	950	650	–
Time required, min.	–	70	288	–
Apparent density, g/cm^3	0.594	0.503	0.490	0.480
Molasses No.	166	173	208	195
Iodine No.	519	845	869	942

CONVERSION OF ADSORBED ABS TO FREE ACID OR SODIUM SALT

Analysis of the spent carbon from the first-column section used for the treatment of aqueous ABS solution at 2.5 gpm per square foot, after the rinsing and drying, showed that it contained 0.85 percent by weight Ca, 0.05 Mg, and 0.11 Na. Corresponding values for the virgin carbon are 0.08 percent Ca, 0.05 Mg, and 0.07 Na. The spent carbon had adsorbed approximately 24 percent of its original weight of ABS. On the assumption of a molecular weight of 350 for the sodium ABS salt, this corresponds to 0.68 milliequivalents per gram of carbon. The comparatively high calcium content of the spent material (0.43 meq/g) and the comparatively low sodium content (0.05 meq/g) can be explained only by assuming that most of the adsorbed ABS is in the form of the calcium salt.

The results obtained by percolating 1 liter of 5 percent HCl through 60 grams of the spent carbon are shown in Figure 8. Analysis of the effluent fractions indicated that approximately 60 percent of the total calcium and all of the magnesium was eluted after 1 liter of effluent was collected. The fact that this is an ion exchange mechanism and not a dissolution of calcium and magnesium salts was demonstrated by two experiments.

First, treatment of a second 60-gram sample of the spent carbon with 1 liter of 5 percent sodium chloride gave elution curves (Figure 8) similar to those obtained for 5 percent hydrochloric acid. Analysis of the effluent fractions indicated that approximately 55 percent of the calcium and 50 percent of the magnesium was eluted from the carbon.

Second, after the hydrochloric acid treatment, 1 liter of tap water containing 13 ppm Ca and 4 ppm Mg was percolated

through the carbon bed. After the acid was displaced, 800 milliliters of effluent containing 2.2 ppm Ca and 0.7 ppm Mg was collected, which indicated that the mechanism is reversible ion exchange.

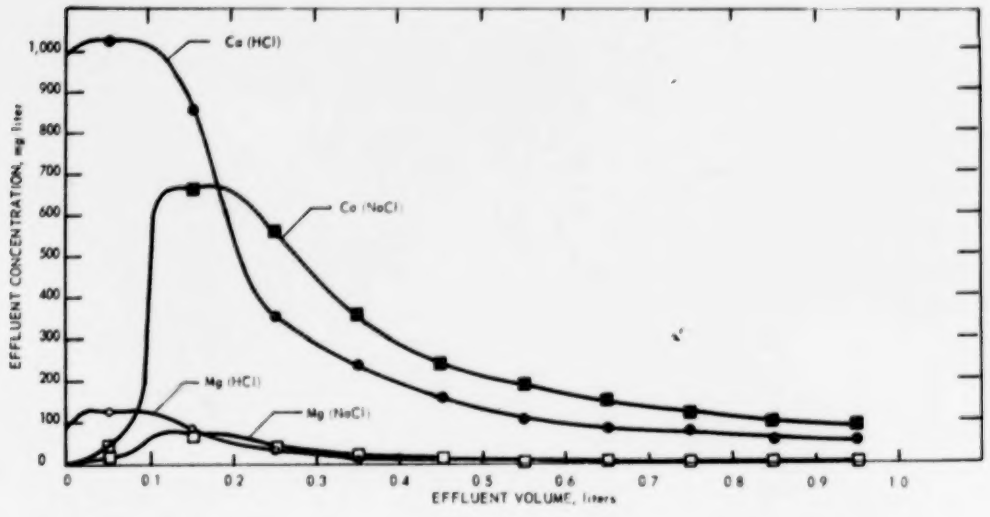

Figure 8. Elution of Ca and Mg from Ca and Mg ABS-saturated carbon with 5% HCl and 5% NaCl.

These experiments were performed to determine the ease with which the adsorbed Ca or Mg ABS could be converted to the free acid or Na salt. It was reasoned that if this conversion could be accomplished prior to thermal reactivation, a water-soluble inorganic residue might be formed and the buildup of insoluble ash minimized. Work in this direction was discontinued because of the difficulty in converting more than approximately half of the adsorbed ABS to the free acid or sodium salt.

Corrosion Test

Examination of the mild steel corrosion test strip after it had been in contact with activated carbon and secondary sewage effluent for 31 days revealed that it was severely pitted. The weight before the test was 14.210 grams and after the test 12.229 grams – a weight loss of 13.9 percent. This corresponds to a loss of 1.365 milligrams per square centimeter per day.

Although additional tests will be necessary before mild steel adsorbers are ruled out, this suggests that consideration be given to the use of internally coated adsorbers.

APPENDIX A.

Pleasant Hills Waste-Water Treatment Plant

A flow diagram of the plant is shown in Figure 9. Raw waste water flows through a comminuting screen to a wet well and from there is pumped to a grit chamber where the retention time is 6 minutes at the design average flow rate of 3.0 mgd. From there the water flows to the primary settling tanks. The retention time here is 1.8 hours. Sludge is withdrawn to hoppers at the influent end by means of a longitudinal and cross-collecting scraping mechanism. Scum and floating particles are removed by revolving scum troughs near the outlet end.

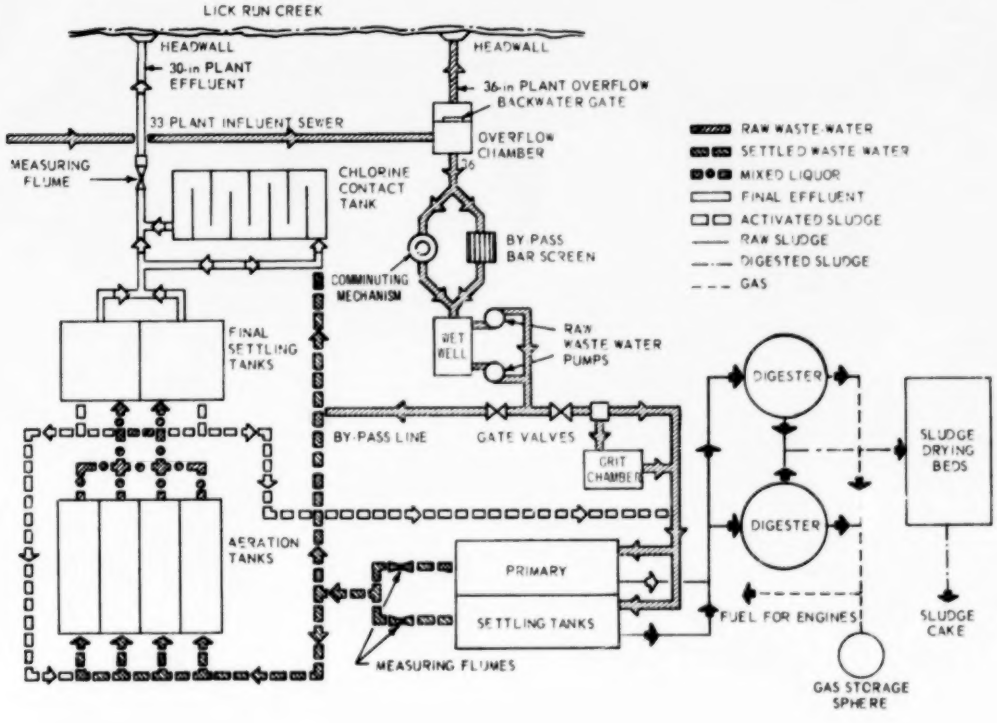

Figure 9. Flow diagram, Pleasant Hills Waste-Water Treatment Plant.

Settled waste water flows from the primary tanks through a series of V-notched weirs into a sludge-mixing channel. Here return sludge from the final tanks, normally 25 percent by volume, is admixed before the waste water goes to the aeration